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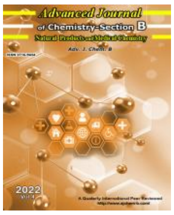

Original Research Article

Investigation of Environmental Processes of Industrial and Municipal Wastewaters

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ABSTRACT

The processes that take place in the collection network have different phases, which are generally complex systems. These processes may occur in various phases, including the fluid phase, the biofilm phase, the wastewater sediment phase, the air in the network, and finally the wall of the sewer wall. These processes have a significant impact on the urban space, for instance, the odorous compounds may be dispersed in the urban atmosphere. Wastewater treatment plants and local wastewater treatment systems are also affected by physical, chemical, and biological reactions in the networks. In addition to receiving discharged materials to the network, these facilities also receive products from network processes such as sludge and treated water. There are several examples that indicate the importance of these processes, for example the effect of sulfide under anaerobic conditions is well known. Sulfide is a serious hazard to humans, a foul-smelling and toxic compound, and may also cause corrosion problems in the network. In addition, anaerobic conditions may result in the production of easily degradable substrates which impair phosphorus removal and de-nitrification in the treatment plant and increase the need for treatment plant facilities. If the collection network is under aerobic conditions, these easily degradable organic materials are removed to produce particles that are easily degradable. Therefore, with proper and efficient design, the conditions governing wastewater during transfer in the collection network may be improved and this potential of collection networks may be used in the removal of wastewater organic matter.

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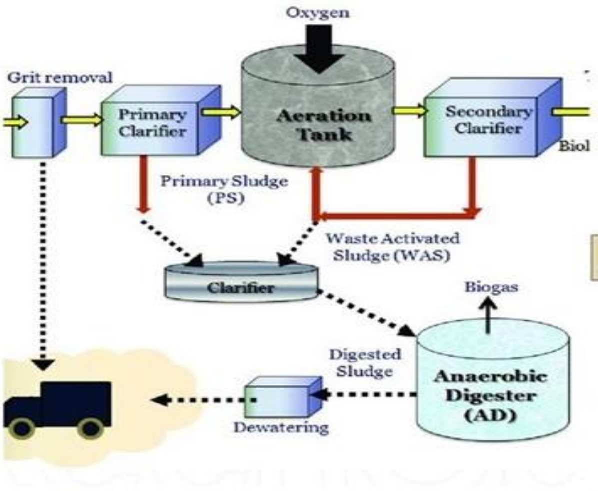
GRAPHICAL ABSTRACT



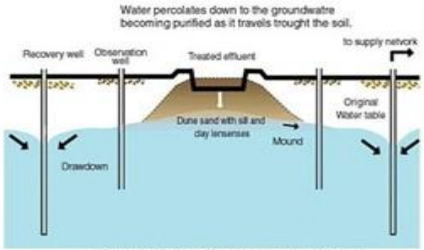
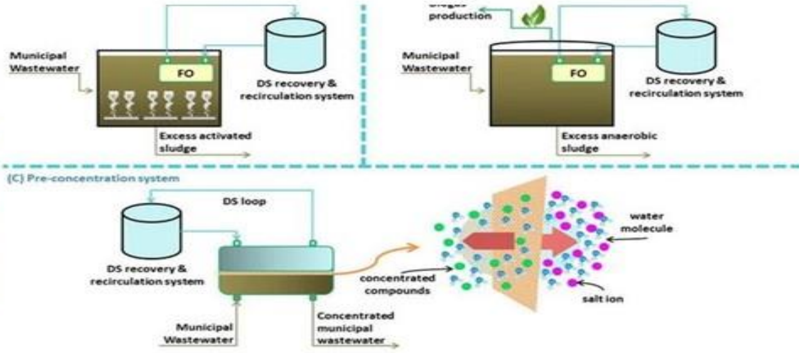


Figure 20: Soil aquifer treatment or rapid-rate land application system



Introduction

Global population growth has created a competitive environment among design engineers in the implementation and maintenance of wastewater collection network and management of such systems, due to the growth of population and per capita water consumption, wastewater produced in cities has increased significantly and designers always [1-3]. They are looking for new ways to design new networks. The above discussion demonstrates that the role of these networks is not only the collection and transfer of wastewater and should be considered as an integral part of the municipal wastewater system, but also in conventional design and executive management, it is assumed that wastewater treatment is completely conducted in the treatment plant and the role of collection networks is merely to collect and transfer wastewater from production sources to the treatment plant [4].

About a hundred years ago, when the relationship between the effect of pathogenic bacteria and microbes on the spread and spread of diseases became apparent, humans began to think about treating contaminated water. The main reason for the development of wastewater treatment and the arrival of this technology in its current form can be considered the progress of biology and medicine [5].

Attention to this technique began when humans were forced to prevent the contamination of natural water resources, especially rivers and freshwater lakes. Therefore, in order to prevent the entry of untreated wastewater into the environment, it was necessary to find the methods for wastewater treatment and their development [6]. Over time, and especially after World War II, as a result of the development of cities and industries, the risk of environmental pollution and due to the need for wastewater treatment increased with unprecedented intensity, and at the same time many methods for wastewater treatment were studied, proposed, and employed. In the evolution of wastewater treatment industry, natural treatment methods can be considered as one of the oldest methods used for treatment [7-9]. Likewise, due to the fertilizer nature of wastewater, its use for irrigation in agricultural lands, has been common in European countries for one hundred years. Raw wastewater always contains physical, microbial, and chemical pollutants, and if discharged to the environment in raw and untreated form, it will pollute water resources, agricultural lands, and the environment, in general. The dangers of environmental pollution are ultimately realized through the food cycle to human health. The severity of water pollution by sewage and effluent will become more apparent when we know that each cubic meter of sewage pollutes 10 to 40 cubic meters of clean water, and it is not only surface water which is exposed to pollution caused by human activities, but also sewage and effluent discharge. On land, it can severely contaminate groundwater. In some cities of Iran, due to such pollutants, the concentration of nitrate ions sometimes reaches up to 3 times the permitted limit of the world standard [10].

The importance of wastewater collection

With the development of cities and the sudden growth of population, as well as the expansion of industries and factories, the issue of environmental pollution is becoming more important day by day which makes them unhealthy and puts their lives in more serious danger. The presence of wastewater is one of the main causes of environmental pollution, so it is essential to collect wastewater produced in residential and industrial areas and transfer it to wastewater treatment plants for treatment (Figure 1). Wastewater collection is necessary from perspectives such as public health, environmental disturbance, groundwater pollution, and reuse of treated wastewater [11].

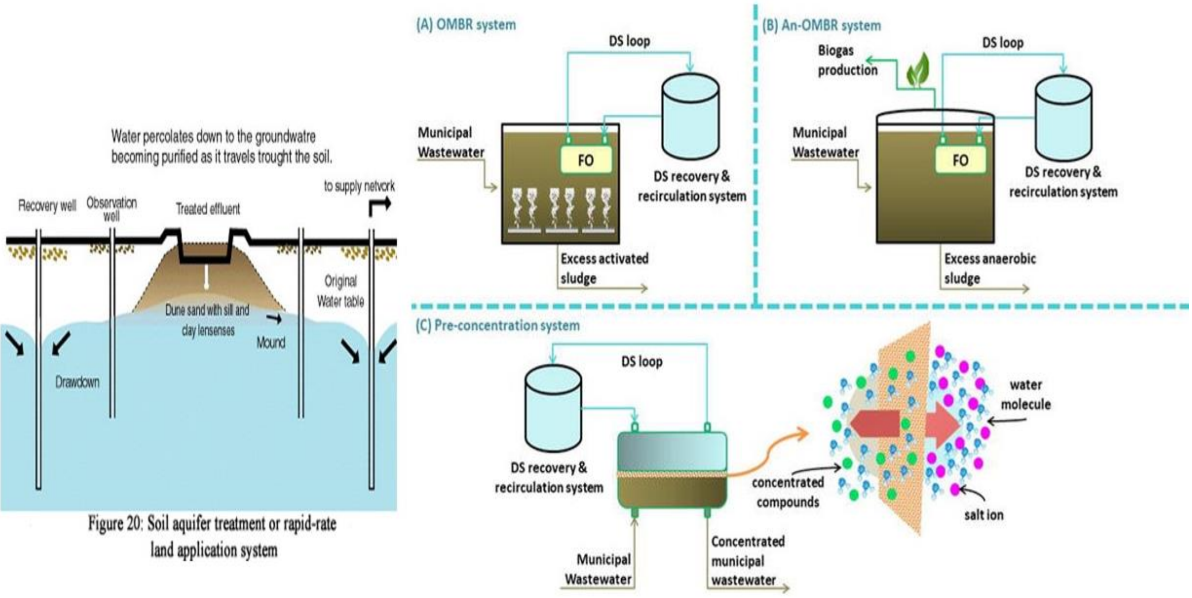


Figure 1. Environmentally Sound Technologies in wastewater treatment

Sewage collection networks

The problem of collecting sewage from the residential environment arose when humans turned to group life. With the advent of cities and the expansion of water supply networks, man encountered the need to collect sewage and effluent to keep his life clean. After the development of water supply network technique, the construction of sewage disposal networks was also considered. The history of the sewage usage dates back to the ancient Iran and Rome. These systems have been used to transport runoff from heavy rainfall in urban areas and to protect cities from flooding. The oldest canalization can be seen in the works of Indian civilization. In these works, which date back to several thousand years ago, the remains of sewers with brick walls or pottery have been seen to direct domestic sewage. In Jerusalem, traces of sewage channels outside the city and its collection in sewage lakes and even the use of sewage as fertilizer in agriculture have been evident, which dates back to about 3000 years ago [12]. Until about a hundred years ago, gutters, especially sub-sewers, were built in the open. In the 16th and 17th centuries, drainage systems began to grow in Europe and the United States. Today, dumping waste into these drains is prohibited. Researchers in the mid-19th century found that excreted humans infected with cholera were transported to drinking water systems. It then became clear that the installation of sanitary and technical sewage collection networks was very effective in reducing epidemic diseases. This feature of collection networks is still valid and today is the main reason for their significant expansion even in developing countries with limited financial resources [13]. In the past, sewage collected in cities was usually disposed of without any treatment. Downstream of the rivers to which the sewage enters, problems such as microbial pollution, odors, dissolved oxygen, and fish mortality were observed. After revealing the effect of such canals in the infectious diseases department, an attempt was made to build all the sewers and sewers underground. Today, some of these problems still exist, and problems such as water accumulation (atrophy) and toxicity of heavy metals have been added. To solve these problems, it was proposed to create wastewater treatment plans at the end of the lines. Although wastewater treatment plants (with varying degrees of treatment) are in use around the world today, the development of treatment plants is still evolving [14-16]. The main canals of the sewage collection network were first built in 1789 in Paris with a length of 36 km. The city of London built an underground sewage collection network from 1832 to 1848 after the cholera epidemic that killed 25,000 people. Then after, Hamburg in 1842, Berlin in 1852, and Frankfurt in 1866 established the given sewage network. Most sewage collection networks and their systems today have been built in the last 50 to 100 years, and older composite systems are still in use. Nowadays, these networks are being improved and are usually equipped with rainwater storage ponds. These developments, which have taken place in the past decades, are a huge investment. Around the world, the efforts are being made to properly design wastewater network and treatment plant infrastructure for the future. We still see advances in technical principles and sustainable solutions. To date, however, there is no idea of replacing wastewater collection and treatment networks [17-19].

Domestic sewage

Pure household wastewater includes sanitary facilities in residential areas such as toilets, washbasins, bathrooms, washing machines and dishwashers, kitchen wastewater, as well as wastewater from washing different parts of the house. The properties of domestic wastewater in a country are almost the same and only their concentration changes with the per capita water consumption (Figure 2) [20].

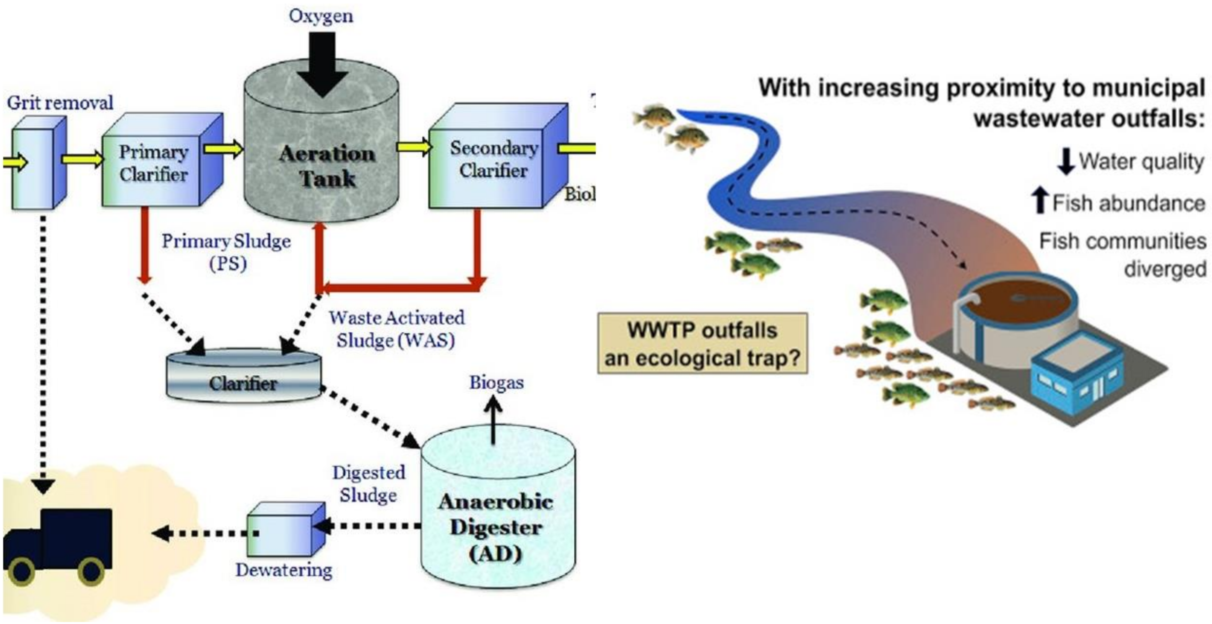


Figure 2. Municipal wastewater effluent affects fish communities

Industrial wastewater

The properties of industrial and factory effluents depend perfectly on the type of factory products, some of which are highly alkaline and acidic, some corrosive and some others are toxic. In wastewater, some factories, such as mining plants, steel mills, and chemical plants are mostly made up of minerals, while in others such as food processing plants and starch factories, most of the foreign matter is in organic wastewater. Pollution from these sewers can sometimes be several times more polluted than domestic sewage [21].

Surface sewage

This wastewater is caused by rain and melting ice and snow in the highlands and due to the flow on the ground, there is some organic and mineral matter in them. Most of the foreign matter in these wastewaters is minerals such as sand and gravel, in addition to the residues of plant and animal particles, petroleum products, and soot are another part of the foreign matter in surface water [22-24].

Wastewater collection networks and its types

Sewage is generated from the water sources of the communities and usually the runoff from the rainfall in the city is directed to the collection network and transferred for treatment and disposal.

The system used to achieve this goal is known as a sewer network or a sewer collection system which includes individual pipes (sewer lines) and equipment to facilitate collection and transmission such as inlet structures and pumps. Safety and economic efficiencies are key criteria in building a collection network, and in the collection of safe wastewater means that public health, welfare, as well as the environmental protection have a high priority. The demand for sustainable water management in cities is a new challenge. Sewage networks change greatly over different periods. During periods without rainfall, the flow rate is influenced by the behavior of the community and usually changes one to ten times during the day and night [25].

During rainy seasons and in sewer pipes which receive municipal wastewater and surface runoff (e.g. composite networks), the flow rate during heavy rains usually increases 100 to 1000 times compared to dry weather conditions. In this regard, many efforts have been made both in practice and in scientific research to develop systems and methods for designing and operating the sewerage network. In the last 20 to 30 years, many efforts have been made to drain the sewer network and have found a comprehensive solution to improve the performance of the treatment plant and the effects of rainfall during rainy seasons. Urban drainage has been the most important issue both in scientific research and in practice [26-28].

Due to the basic requirements of collection and transmission, sewage networks physically deal with phenomena such as hydraulics and transfer of wastewater solids. From this viewpoint, new design and operating principles have been largely developed by numerical methods and by computers. The network design and operation is very influential on the collection network processes, so when designing wastewater collection networks, one should be perfectly aware of the processes which take place in these networks. For instance, network ventilation can affect the accumulation and dispersion of toxic odors produced by biological processes [29].

Sewage collection networks are divided into three main categories including sanitary sewage networks (separate networks), rainwater collection networks, and composite networks, each of which has specific characteristics from a process viewpoint, which are described in the following [30].

Sewerage networks

These networks are often known as separate networks and are used to collect wastewater from residential, commercial, and industrial areas. Sewage flowing through these networks usually has a relatively high concentration of biodegradable organic matter and is therefore biologically active. Regarding the process, this wastewater is a combination of biomass (especially heterotrophic bacteria) and nutrients (substrate). In practice, such networks may also receive some surface runoff. Flow in separate sewers may be controlled by gravity (gravity network) or pressure (pressurized networks) [31].

In semi-full gravity sewers, oxygen transfer from the air-air contact surface is possible and aerobic heterotrophic bacteria may be active. In contrast, the current in pressurized networks is completely full and there is no possibility of oxygen transfer. In this type of wastewater, the predominant process is the anaerobic process and the degree of biological transformation depends on the duration of the wastewater flow inside the network (retention time). Sewage retention time in the network depends on the size of the catchment and the characteristics of the sewer, such as slope and length, which is relatively high in pressurized networks, especially at night [32].

Surface water collection networks

These networks are used to collect and transport surface sewage (rainwater) which originates from impermeable surfaces such as streets, highways, and parking lots. Surface water usually enters these networks through the inlet structure, which is located in the street drainage. These networks operate only in rainy conditions and usually transfer the rainwater to the receiving environment without any treatment or with partial treatment. In these collection networks, microbial and chemical processes are rare and have little effect. On the other hand, in structures such as water storage pools, as part of this network, both chemical and biological treatment processes occur [33].

Composite collection networks

In these networks, municipal wastewater and surface runoff are collected and transferred to the treatment plant. During periods of dry weather, the system generally acts as a separate collection network in terms of chemical and biological processes. However, the design of these networks differs from that of separate networks due to their ability to collect surface runoff and include components such as overflow structures and water basins which may affect process details. In addition, the processes of composite networks are more varied than those of individual networks due to the regular changes in flow conditions. Composite collection networks may be designed and constructed by gravity, pressure, or their combination. In addition to the above networks, there are alternative collection network systems such as vacuum networks and small diameter gravity networks, which are usually small and locally used [34].

Alternative collection networks

Alternative wastewater collection network systems are used in areas where it is not possible to implement conventional wastewater networks. These networks are very suitable for places that are full of hills or completely flat, because in these places, deep drilling is required and as a result, the operating costs are greatly increased. There are different types of alternative networks, which are referred to only as small-diameter gravity collection networks [35].

Small diameter gravity collection nets

Small diameter gravity collection networks are one of the alternative systems for conventional networks which transfer the effluent from septic tanks by gravity to treatment plants. In this type of networks, plastic pipes with smaller diameters are used and the installation depth of the pipes is less than conventional gravity networks. These networks are suitable for areas with low population density, rural areas, and places with seasonal populations. The organic load transferred in these networks is relatively lower than conventional wastewater collection networks, because some of the suspended organic matter is removed in the septic tanks. The typical diameter of these nets is 80 mm or 3 inches, however it is better to choose a minimum diameter of 100 mm. In these systems, there is no need to observe the minimum speed because the materials deposition is not one of their design parameters [36].

Types of methods used to investigate wastewater collection network processes

Thorkild et al. have been very active in this field and in their book, entitled physical, chemical, and biological processes in collection networks; they have described the correct way of conducting research in this field. In this research, the key points and basic concepts of this book have been used a lot. Therefore, one of the main sources of the dissertation can be mentioned in this book.

In the following, different methods of collecting network processes are discussed. The methods used in the study of wastewater collection network processes, in general, can be classified as follows:

1- Small scale laboratory analyzes entitiled laboratory reactors.
2- Laboratory pilot projects.
3- Field studies [37].

Laboratory analysis in small reactors

Small reactors may only be able to determine a specific parameter in some cases. These methods are generally based on standard methods for evaluating water and wastewater. Process studies are usually performed discontinuously or with continuous reactors.

One of the general and important aspects of laboratory studies is that they can be performed under controlled process conditions. Reactors used for laboratory studies should be built with high precision. In addition, a detailed schedule is required for sampling, navigation, and analysis. Tests performed in a reactor require planning as well as general experience to achieve the goal and success. The purpose of building this reactor is to study the rate of nutrient removal (acetate was considered in this experiment) and dissolved oxygen by the biofilm formed in the wastewater.

To achieve this goal, the precise control is required during the experiment, because both dissolved oxygen and acetate concentration have been studied as reducing factors and the aim has been to calculate their removal rate [38].

Laboratory pilot projects

Laboratory pilot projects are like small laboratory reactors to control the conditions of different factors, each of which affects the process under study. The main advantage of laboratory pilot projects over small laboratory reactors is that they are closer to the real system and their disadvantage is the need for more laboratory resources and equipment. Such pilots are often more difficult to set up and may require special experimental skills.

Field studies

Collection networks are not suitable systems for partial process studies because they have limited capabilities under controlled conditions. These studies are generally used to determine parameters which cannot be explicitly measurable on a laboratory scale.

This type of research is usually carried out by sampling upstream and downstream stations as well as by measuring changes in route. Sewage volume can be obtained through tracker studies. Materials such as rhodamine, radiotherapy, and salt are commonly used. It is better to conduct field studies on long sewer lines, which causes relatively large differences in the characteristics of the sewer. Finally, in order to facilitate the sampling program and determine the entry and exit points, sewer lines without tributaries, without leaks, and tributaries should be used [39].

Although the management of wastewater field studies is difficult and generally not scientifically ideal, for some reason their results are needed because these systems indicate real performance and also their results are needed to calibrate laboratory results. To assess the impact of rainwater runoff on composite networks, Gasperi et al. surveyed six urban areas in Paris. They examined parameters such as TSS, COD, BOD, heavy metals (including CU and Zn), TKN, and polycyclic aromatic hydrocarbons (PAHs). To achieve this goal, they examined 16 cases of rainfall. The area of the urban areas was variable and ranged from 42 to 2581 hectares. Mass balance at the inlet and outlet of the target areas illustrates that wastewater is the main source of pollution from organic matter and nitrogen, while runoff is the main source of zinc [40].

Qualitative changes in wastewater during transfer

First of all, it should be noted that the biofilm structure formed in the collection network is very different from the one in conventional treatment plant processes. This difference is due to the presence of high organic load in the networks as well as shear stress on the biofilm surface (due to high flow velocity). The following is a general overview of wastewater treatment.

Wastewater treatment in the vicinity of aerobic bacteria

If enough oxygen reaches the wastewater regularly during decomposition, aerobic bacteria begin to decompose and act. In this process, carbonaceous organic matter is first consumed as an energy source by microorganisms, then “volatile compounds are converted to ammonia, and after that to nitrite and nitrate.”

Types of reactions of gravity collection networks under aerobic conditions

In aerobic treatment systems, microorganisms require dissolved oxygen to biodegrade the organic matter of wastewater. The concentration of dissolved oxygen is a function of the rate of air supply to these networks as well as the rate of dissolved oxygen consumption by microorganisms.

In some cases, in which the amount of dissolved oxygen in these networks is not enough, the aerobic microorganisms will not be able to decompose the COD of the wastewater solution, and this condition will cause odorous and corrosive compounds. Therefore, it should be ensured that in the wastewater collection networks, sufficient dissolved oxygen is available to prevent anaerobic conditions. Arsin Casirga et al. investigated the possibility of wastewater treatment in long collection networks in the presence of sufficient dissolved oxygen. They studied the kinetics of adduction and suspension growth to determine the amount of aeration required in the networks.

Although various models were proposed to describe the mechanism of organic matter consumption and reaction rate, they proposed a new model for minimizing the required parameters in biological rate equations. Consumption of soluble substrate by suspended microorganisms was used by laboratory studies and the relationship between consumption rate and concentration of degradable organic matter was studied, too. Finally, they presented an experimental relationship that indicated the relationship between consumption rate and substrate concentration in collection networks.

Decomposition of wastewater organic matter under anaerobic conditions

When oxygen is not in the vicinity of sewage, the aerobic bacteria will no longer be able to survive and use food. In this case, anaerobic bacteria are able to use the oxygen of organic matter enter. Thus, the decomposition of materials due to the presence of anaerobic bacteria leads to the formation of organic acids, acidic carbonates, carbon monoxide, and hydrogen sulfide. Torkild et al. examined aspects of the release of volatile compounds into wastewater collection networks. In this case, they presented a model based on the evaluation of sulfide formation and total sulfide concentration in the wastewater phase. They investigated the factors influencing the formation of hydrogen sulfide gas, the formation of odors due to fermentation processes, mass transfer in the aqueous phases, and the release of volatile compounds. They also predicted the rate of sulfide production in collection networks through the existing experimental equations.

How H_2S gas is formed in wastewater

Sulfides are present in wastewater in various forms (S^{2-}, HS^{-1}, and S^{2-}), and the concentration of which depends on the PH of the wastewater. Sulfate-reducing bacteria (SRBs) break down sulfate compounds and eventually produce hydrogen sulfide gas. H_2S gas escapes from the sewer surface and settles on the surface of the pipes. Exhausted H_2S is converted to sulfuric acid in the moisture presence. The produced sulfuric acid penetrates the concrete surface and forms calcium sulfate, which is a corrosive compound. Factors influencing the occurrence of corrosion can be dissolved oxygen, temperature, SO_4^{2-} ion concentration, slope and flow velocity, retention time, depth, and hydraulic radius. In the biological process under anaerobic conditions, the storage of sulfides is in the form of sulfate, sulfite, and thiosulfate, and its reduction in the form of sulfide is done by declining bacteria in the cytoplasm. H_2S gas production in the network indicates the biological reactions performed by bacteria in the network and demonstrates the ability of wastewater collection networks to perform biological reactions.

The effect of nitrate in controlling anaerobic conditions

Anaerobic conditions can be controlled by adding nitrate (NO_3^-) to the networks. In some cases, however, the excessive addition of nitrogen causes the biofilm to grow in the inner wall of the pipes, leading to de-nitrification in the sedimentation facility.

Under these conditions, due to the production of N_2 gas, the sludge of the residential facilities is suspended and removed from the system.

Therefore, due to the operational difficulties of adding nitrate, adding oxygen to the collection networks seems to be more efficient.

Zhiguan Yuan et al. studied the deformation of sulfur under anoxic and anaerobic conditions by the addition of excess nitrate in a laboratory model of pressurized collection networks.

For this, they used four reactors which operated in series and expressed the strategy of adding nitrate in effective sulfide control. Sulfide oxidation under anoxic conditions occurs in two sequential stages:

1- Oxidation of sulfide to elemental sulfide (SO).

2- Oxidation of elemental sulfide to sulfate (SO_4^{2-}).

The second stage occurs when the first stage is complete and the rate is about 15% of the first stage rate. When nitrate is not available, the sulfate and elemental sulfur are reduced together as sulfides.

The rate of sulfate reduction was essentially higher than that of elemental sulfide (five times). The low oxidation rate and reduction of elemental sulfur show the importance of this intermediate product in the deformation of sulfur under anoxic and anaerobic conditions. They also presented a conceptual model of sulfur deformation under nitrate addition to pressurized networks. Likewise, Zhiguan Yuan et al. used laboratory studies to simulate pressure grids to observe the effect of oxygen injection on the sulfide control of networks. Their results indicate that oxygen transfer at the inlet of the networks (with a concentration between 15-25 mg/l) can reduce sulfide production by up to 65%. Although increasing the oxygen concentration is effective in the sulfide production process, it cannot stop this process completely because sulfide production continues in the biofilm substrates, regardless of the high oxygen concentration in the aqueous phase. They also observed that increasing the oxygen concentration increases the oxygen consumption rate in the network, which also leads to the removal of more organic matter.

The optimizing oxygen transfer is therefore necessary to increase its effect on sulfide control.

Yuan et al. also used a laboratory pilot to investigate the effect of nitrate addition on the biofilm properties and activity of pressurized wastewater collection networks. They concluded that nitrate addition did not reduce the microbial population of sulfate-reducing bacteria in the collection network biofilm, but rather increased the activity of these bacteria in the downstream biofilm. According to their results, nitrate addition, as a whole, has been effective in controlling the sulfide concentration in pressurized networks. They report that the addition of nitrate after a short period of time for adaptation stimulates the oxidation of biological sulfide in the biofilm. They also concluded that adding nitrate was very effective in reducing methane concentrations.

Hanchan Shi and his colleagues worked to remove sulfide from collection networks due to the anaerobic conditions. To achieve this goal, they periodically investigated the effect of adding nitrate in a model of wastewater collection networks. Their results indicate that the best control conditions are when the nitrogen to sulfate rate is at least between 0.5 and 0.6. Zhiguan Yuan et al. used three laboratory reactors in which anaerobic biofilm growth conditions were established to investigate nitrate effect being added to the networks as a reducing agent for anaerobic conditions. The results indicate that the effect of nitrate as a reducing agent of anaerobic conditions is due to the biocidal effect of free nitric acid (FNA), the proton form of nitrite on the biofilm microorganism. They examined the microbial activity of wastewater at zero to 120 mg/l nitrite at PH 5 to 7. The viability of the microorganisms was reduced by approximately 80% during the 6 to 24-hour residence time, at which point the FNA concentration was more than 0.2 mg nitrite per liter.

Conclusion

Increasing the oxygen concentration is done by adding air or injecting pure oxygen, trying to keep the wastewater in the aerobic phase, and preventing anaerobic conditions. If dissolved oxygen is present around the wastewater biofilm, the chemical and biological oxidation of the sulfide takes place, and conversely, in the absence of dissolved oxygen, the dissolved sulfide is transferred from the biofilm to the wastewater, in which it is present in the form of hydrogen sulfide. Soluble oxygen concentration of more than 0.5 mg/l generally prevents the formation of soluble sulfide in wastewater. The dissolution of pure oxygen is five times the dissolution of oxygen in the air, which makes it possible to achieve the required oxygen concentration with pure oxygen. By pure oxygen injection, the concentration of dissolved oxygen in the effluent usually reaches 5 to 7 mg/l, while the injection of air increases its concentration in the effluent to about 3 to 5 mg/l.

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